CASE STUDIES OF VENTILATION RETROFITS DESIGNED TO RESOLVE AIR QUALITY PROBLEMS IN PUBLIC BUILDINGS

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ABSTRACT

Ventilation air distribution problems involving system design, installation, operation and maintenance are often suspected of causing air quality problems that plague many modern sealed office buildings. Such air quality problems have resulted in occupants suffering symptoms of discomfort and ill health. Three case studies are described in which tests of ventilation performance appear to relate poor air quality to air distribution and ventilation. In all cases, ventilation system retrofits were designed to improve indoor environmental conditions.

INTRODUCTION

Hundreds of "sick buildings" have been investigated throughout North America since the mid-1970s. Many investigations were motivated by occupant health and comfort complaints, such as irritation of the eyes, nose, and throat, headaches and fatigue, and stuffiness and dryness of the indoor air.

Review of investigations by NIOSH (Wallingford et al. 1986) and Health and Welfare Canada (Kirkbride 1985) have shown that ventilation inadequacies, including system design, installation, operation, and maintenance, are often suspected as causal factors for occupant health and comfort complaints.

Three case studies in which ventilation inadequacies were found to be causing poor indoor environmental conditions resulting in occupant health and comfort problems are described. In each case, ventilation system retrofits were recommended to improve environmental conditions. Many of the recommended retrofits either have only recently been completed or have not yet been implemented. Therefore, detailed follow-up evaluation has not been possible. However, qualitative assessment based on reports from building occupants, owners, and/or operators about environmental conditions in the buildings suggests that the retrofit actions have been successful.

CASE ONE: CANADIAN PUBLIC LIBRARY

Background

Occupants of a public library in a Canadian city have had a history of complaints and discomfort since construction of the building. Problems of drowsiness, headaches, eye irritation, dizziness, and nausea have been reported. There has also been a persistent problem of odors in the library, which occupants have identified as traffic fumes and restaurant odors.

Past investigations of occupant concerns in the library have recognized a problem of odors/fumes entering into the library area from outdoor air intakes located at street level.. The building managers had decided to install an air purification (activated carbon) filter. An in-

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vestigation was undertaken to assess the effectiveness of the filtration solution by investigating conditions in the library before and after installation.

Building Description

The library is located on the main floor of a four-story office complex. A three level parking garage is located beneath the offices. The mechanical system is a constant volume, dual duct multizone system with terminal boxes controlled by zone thermostats. The library is divided into three ventilation zones, which are shown in Figure 1.

1. Northwest zone - outside air intake at street level

2. Southwest zone - outside air intake at street level

3. Southeast zone - outside air intake on second floor level

Ventilation air is supplied to the library through ducting mounted on the exposed underside of the above floor to circular diffusers. Each zone has one ceiling exhaust grille.

Past investigations of the library had focused on the problem of odors/fumes entering the office space. However, past results (specifically carbon dioxide measurements and the types of health and comfort complaints reported by occupants) have suggested an additional problem of poor supply air distribution.

Approach

The investigation focused on three main issues:

1. The infiltration of pollutants, specifically exhaust fumes, from outdoors and the underground parking garage. Other investigations of office buildings have shown a substantial problem of infiltration of carbon monoxide from underground parking garages (Sterling et al. 1985).

2. The effectiveness of the filter installation in improving environmental conditions in the building.

3. Supply air distribution within the space.

Carbon monoxide (CO) was measured throughout the library and outdoors as an indicator of the infiltration of pollutants from outdoors and from the underground parking garage.

Carbon dioxide (CO_2) was measured as an indicator of the efficiency of the mechanical ventilation system in removing indoor generated contaminants and circulating air through the occupied space.

Results

Measurements and observations taken prior to the installation of the activated carbon filter indicated that the majority of occupant complaints about restaurant and traffic odors were concentrated in the northwest ventilation zone. CO concentrations were higher in this zone than in the other two zones (approximately 5 ppm). Indoor CO concentrations appeared to be strongly influenced by the outdoor CO concentrations measured in the vicinity of the outside air intake. There did not appear to be a relationship between CO concentrations measured in the library and in the parking garage.

Inspection of the outside air intake for the northwest zone confirmed its location at street level on a busy downtown street. The intake was also located adjacent to a commercial loading zone and a restaurant. After installation of the activated carbon filter, occupants reported that the number of odor episodes had been reduced, although automobile exhaust odors had still been apparent on several occasions. Measurements showed that the installation of the filter had no effect on the CO concentrations in the northwest zone. This finding is not surprising because an activated carbon filtration medium will act to remove the volatile organic compound components of traffic exhaust, but it will not effect carbon monoxide.

Carbon dioxide concentrations in the library ranged between 500 ppm and 700 ppm. Measurements were taken at both the ceiling and desktop level to determine air distribution patterns.

Lower CO_2 concentrations at the ceiling height compared to desktop height indicated that the ventilation air is not being effectively distributed to the occupied zone, causing a problem of stratification. At four of the six sampling locations in the library, desktop CO_2 concentrations were more than 100 ppm higher than ceiling levels. These results show that stratification problems occurred throughout the library.

Retrofit Recommendations

The investigation concluded that:

1. Although the installation of the activated carbon filters had decreased the incidence of odor epidodes, a potential for air quality problems remained due to the location of the fresh air intake at street level.

2. A problem of stratification existed in the library.

3. The infiltraiton of CO into the library from the parking garage was not found to be a problem. However, CO concentrations in the parking garage were elevated. As a result, follow-up investigation of the garage was recommended. The results of this follow-up are reported in Case Two.

Based on these findings, retrofit actions were designed to improve environmental conditions in the library. To improve the quality of the outdoor air supply, a recommendation (including design plans) was made to relocate the fresh air intake from street level onto the rooftop. To improve air distribution, a lowering of the ceiling diffusers by removing the existing vertical ducts to the diffusers and installing a three-foot long vertical duct and then reinstalling the diffuser were recommended. This method was considered preferable to simply increasing the velocity of airflow through the diffusers.

CASE TWO: CANADIAN CITY PARKING GARAGE

Background

During the investigation of indoor environmental conditions of a library in a Canadian city (reported in Case One), a potential problem of a buildup of carbon monoxide (CO) in the underground parking garage was identified.

Building Description

The parking garage is a three-level underground structure, with a total floor area of 184,000 ft^2. Figure 2 shows the basic layout of the garage. The levels are marked 1, 2, and 3. Level 1 is just below street level and levels 2 and 3 are progressively lower. Traffic enters and exits Level 1 through portals on streets to the north and south. The garage has two traffic circulation spines, which run along an east-west axis and spiral between levels.

Review of mechanical plans showed that substantial modifications to the fan configurations had been implemented since construction of the garage.

The original (pre 1981) fan configuration is shown in Figure 3. This ventilation system configuration incorporated 24 fresh air vents and 13 exhaust vents. Air flow in the garage was intended to flow from the supply vents on the west side of the garage to the exhaust vents on the east side. The configuration was intended to create positive pressurization that would also force exhaust air out of the two street entrances. However, this configuration created a potential for entrainment of exhaust fumes into the office building above. Fresh air intakes for the upper floors of the building were located directly above the parking garage entrances. Consequently, the ventilation configuration was modified to the current situation.

The current fan configuration is shown in Figure 4. On all three levels of the garage, the supply fans are located on the south side and the exhaust fans are located on the north and east sides. This modified configuration was intended to promote a transverse airflow from the supply vents on the south wall to the north and east wall exhausts.

Approach

As a result of concerns about poor air quality in the parking garage, an investigation was undertaken to determine whether CO concentrations in the parking garage were elevated to a level that could constitute a health problem. The investigation consisted of two parts:

1. Review of ventilation system design and operation, including both the original and modified fan configurations.

2. Continuous and spot measurements of CO at locations throughout the parking garage and outdoors over a two-day period.

Results

The amount of outside air per unit area of floor space being supplied to the parking garage by the original and modified fan configurations was calculated using design specifications from the mechancial plans. The results are shown in Table 1. The amount of outside air supplied to each level of the parking garage for both the original and modified fan configurations was substantially below the ASHRAE 62-1981 standard of 1.5 cfm/ft^2 (ASHRAE 1981).

Visual inspection of the parking garage indicated that the transverse airflow from the supply vents on the south wall to the exhaust vents on the north was impeded by the spiraling design of the vehicle pathways in the garage which acted as a barrier to effective airflow.

Results of the CO measurements showed a peak concentration of 125 ppm on level 1 during the afternoon rush hour at a location on the north side of the garage. Conditions monitored at this location showed that for a 25 minute period during rush hour, CO concentrations on level 1 remained above 100 ppm. CO levels varied by the time of day and location relative to the supply and exhaust vents. The highest concentrations were found on the upper two levels on the north side of the garage. In these locations, eight-hour time-weighted averages were 28.8 ppm on level 1 and 26.1 ppm on level 2.

The CO concentrations found in the parking garage were blow established indoor air quality standards for the industrial workplace (for example, the ACGIH and NIOSH one-hour mean concentration of 400 ppm and the eight-hour mean of 50). However, the concentrations were above guidelines for both the nonindustrial environment established by the World Health Organization (27 ppm, one-hour mean) and ambient air established by the U.S. Environmental Protection Agency (36 ppm 1 hour mean, 9 ppm, eight-hour mean).

Retrofit Recommendations

The investigation concluded that:

1. The transverse airflow pattern was not effective due to the spiraled design of the vehicle pathways. A consequence was elevated CO concentrations toward the north side of the garage.

2. The amount of outside air supplied to the garage did not meet the ASHRAE 62-1981 requirement of 1.5 cfm/ft^2.

The retrofit actions recommended to improve conditions involved the alteration of the fan arrangement in order to enhance the "stack effect," resulting in airflow patterns up the helical roadways. The recommended fan configuration is shown in Figure 5.

Fresh air would be delivered to all fans on level 3 and six fans on level 2. The remaining fans on level 2 and all of the fans on level 1 would be exhaust. This change in configuration would allow airflow patterns to utilize the roadway design of the garage rather than the roadway acting as a barrier to airflow. The recommended configuration would also increase the amount of fresh air to a level that complies with ASHRAE standard 62-1981 (ASHRAE 1981).

CASE THREE: NORTHERN U.S. OFFICE BUILDING

Background

Two occupants of an office building in a northern U.S. city reported acute respiratory problems during October 1985. Medical examination suggested that the occupant health problems may have been related to the workplace and identified molds as a possible cause. Following the medical diagnosis, state investigators conducted a number of studies, including an industrial hygiene survey and a questionnaire survey. Based on the findings from the state studies, the building was evacuated in February 1986, and in the months following, several consultants were commissioned by both the building owners and the state to investigate HVAC system design and operation and possible microbial contamination of the system.

Building Description

The office building is a three-story structure with a net usable floor space for 48,640 ft^2. The building is serviced by two multizone rooftop-mounted HVAC systems. Ventilation air is ducted to ceiling-mounted diffusers through fiberglass board horizontal ducts. Return air is exhausted through ceiling grills into a common ceiling plenum. Supplimental heating in the building is provided by baseboard electric units. Smoking was not permitted in the building.

Approach

Investigations of the mechancial systems, conducted by several consultants, included:

1. Review of HVAC system design and operation.

2. Physical inspection and airflow measurements of the HVAC system.

3. Biological sampling of the indoor air, building furnishings and equipment to determine whether the system was microbially contaminated.

Results

Review of the mechanical plans and airflow measurements showed that the system was delivering air in compliance with ASHRAE Standard 62-1981 of 5 cfm/person for a nonsmoking building.

Inspection of the two rooftop air handling units showed an accumulation of fine dark dust throughout both units. The condensate pans under the supply fans and air conditioning units contained a sludgelike material and the design of the pans allowed standing water to accumulate. A potential for reentrainment of exhausted air was also observed.

Inspection of the fiberglass ducts and the diffusers showed a coating of dark dust. The dust had also appeared to penetrate into the fiberglass diffuser liners.

Sampling of the dust found in the air handling units, the ducts, and diffusers showed no microbial contamination. The sludge retrieved from the condensate pans was contaminated with the fungus, Phoma. Although this was identified in the sludge, Phoma was not identified in airborne samples. Such results suggest that the cause of the occupant health problems may not have been linked to the mechanical ventilation system.

Microbial sampling was also performed on building furnishing materials and equipment. In the heavily trafficked areas of the building, carpeting was found to be substantially contaminated. Microbial contamination was also identified in electrostatic precipitators in waiting rooms (electrostatic precipitators were installed by the tenants even though the building was designated as nonsmoking to eliminate odors produced by a high density of welfare clients) and four portable cool mist humidifiers, also installed by the tenants. Microbial contamination identified in the carpeting and equipment installed by the building tenants may have been causal agents.

Retrofit Actions

The investigations of the HVAC system concluded that:

1. The mechanical system complied with existing ASHRAE standards for a nonsmoking building.

2. The rooftop air-handling units, the fiberglass ducts and diffuser lines were dusty but were not microbially contaminated.

3. Carpeting in heavily trafficked areas and equipment such as electrostatic precipitators and humidifiers were microbially contaminated.

4. There was a potential for reentrainment of exhaust air in the rooftop units.

Retrofit actions were designed to address the identified problems. Recommended retrofit actions included:

1. Airflow balancing of the mechancial system.

2. Although the mechanical system compled with ASHRAE 62-1981, recommendation was made that it should also comply with the proposed revision, ASHRAE standard 62-1981R, which requires a minimum of 15 cfm/person of outside air in both smoking and nonsmoking buildings (ASHRAE 1986). To achieve this, a third rooftop air handling unit has been installed.

3. Cleaning of the rooftop air-handling units, including the removal of the fiberglass insulation, thorough cleaning with a dilute bleach solution and replacement of new insulation.

4. Redesign of the condensate pans in the rooftop units to alleviate the problem of standing water.

5. Cleaning of the diffusers with a dilute bleach solution and a HEPA filtered vacuum, and the replacement of the acoustic insulation in the diffusers.

6. Removal of carpeting in heavily trafficked areas and also the electrostatic precipitators and humidifiers.

7. Redirection of the exhaust vents on the rooftop units to eliminate the potential for reentrainment.

These retrofit actions have subsequently been implemented. Although detailed follow up evaluation has not been conducted, the building has been reoccupied and walk-through inspection has suggested that the actions have been successful in improving environmental conditions.

DISCUSSION

The three case studies provide examples of how ventilation system inadequacies can lead to occupant health and comfort problems. The investigations also provide practical examples of retrofit actions designed to improve indoor environmental conditions.

A thorough investigation should also determine the effectiveness of recommended retrofit actions in improving environmental conditions. Unfortunately, building owners and operators are often hesitant to perform follow-up evaluations after modifications have been implemented. Reasons for this may include the additional costs incurred or concern that the problems have not been solved or that further investigation may identify additional problems. However, it is vital to the problem solving process that investigators, building owner/operators and occupants. It is incumbent upon the responsible parties to cooperate and determine whether or not modifications have actually improved conditions in a building.

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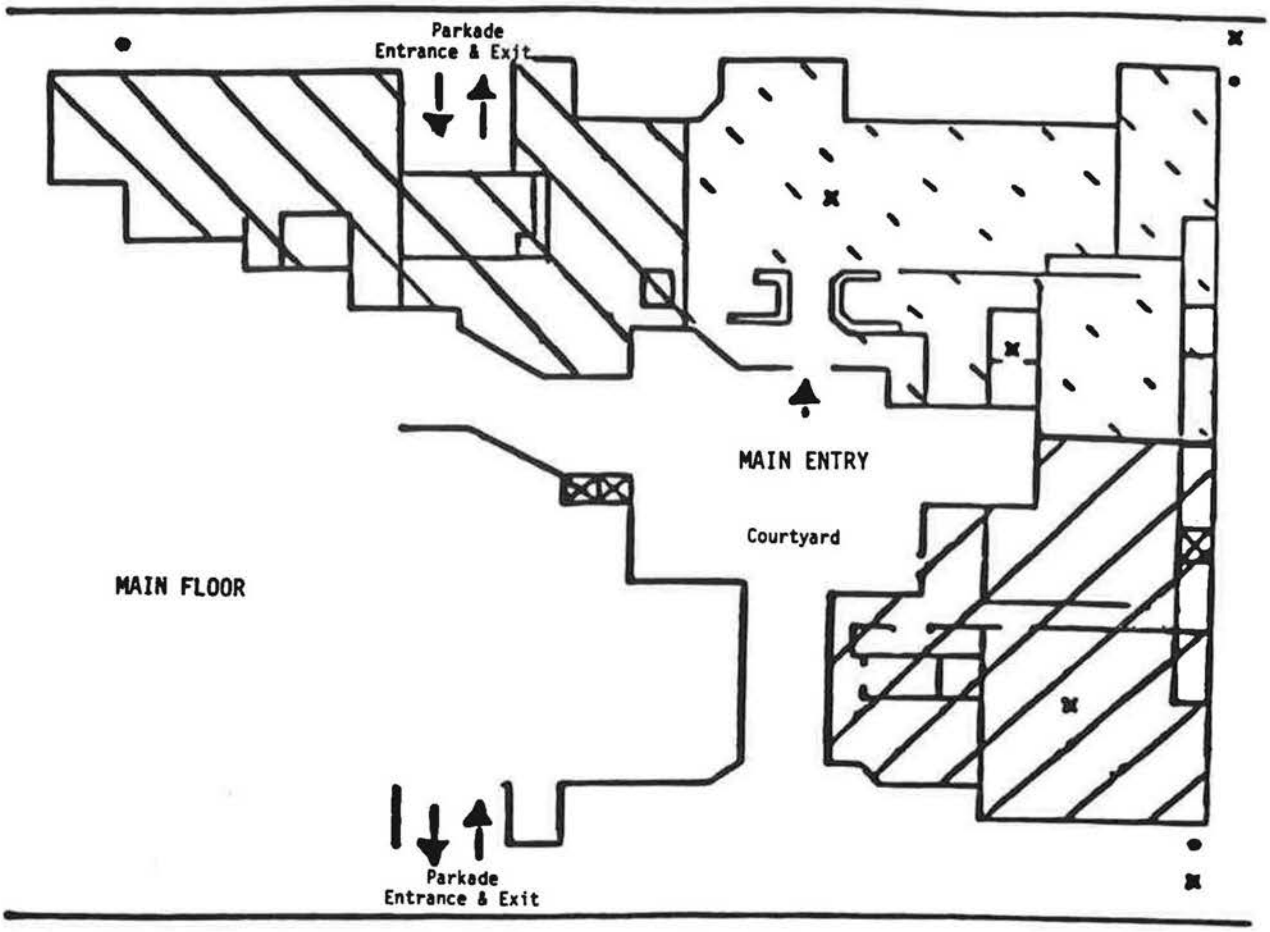
TABLE 1

Fresh Airflow Rates Supplied to Each Level of the Parking Garage, Calculated from the Mechanical Plans

Parking Level	Fresh airflow from original mechanical plans (cfm/ft²)	Fresh airflow from current mechanical configuration (cfm/ft²)
1	0.87	0.43
2	0.83	0.52
3	0.83	0.41



/ Air supplied by Street A (street level) intake

`\ Air supplied by Street B (street level) intake

\ Air supplied by Street B (second floor) intake

• Air intake

x Sampling site

Figure 1. Floor plan of the public library

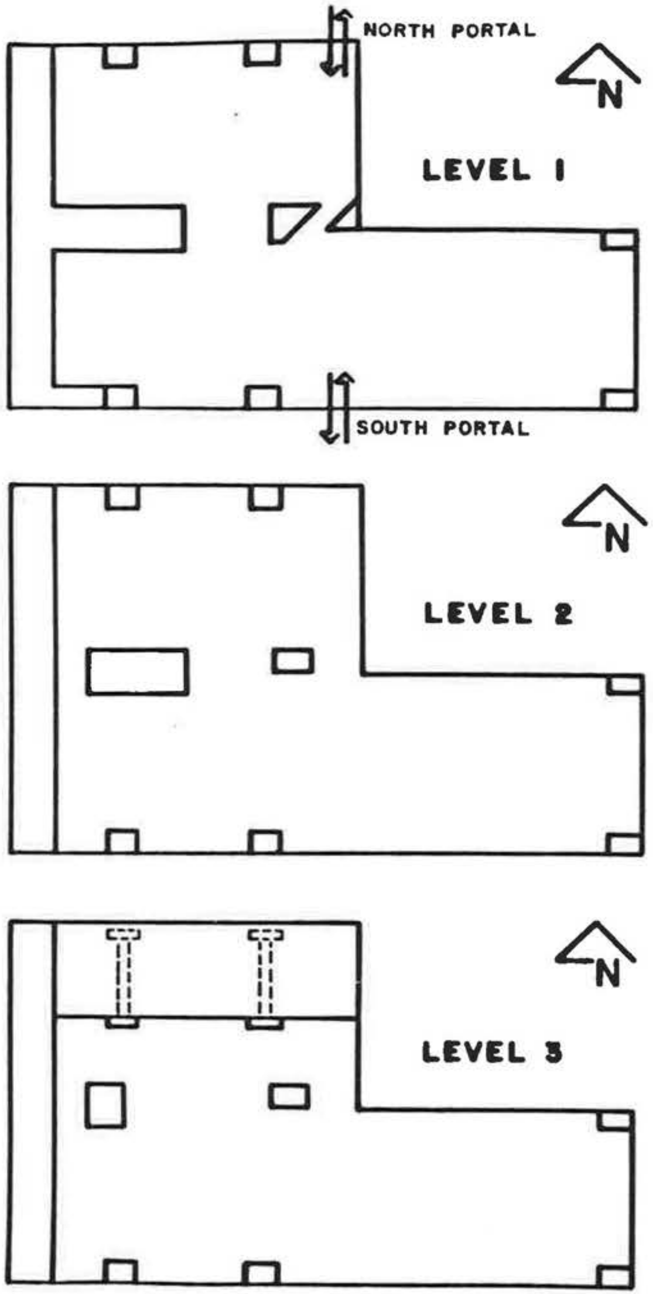


Figure 2. Floor plan of the parking garage

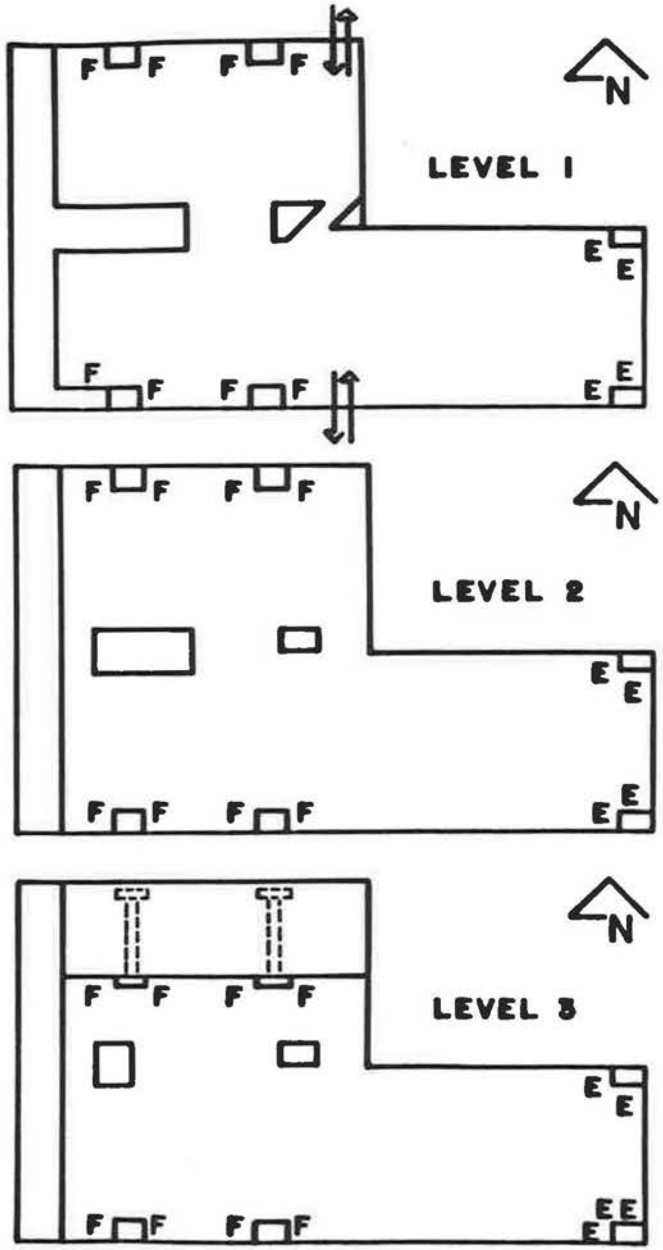


Figure 3. Original configuration of fans in the parking garage; F denotes fresh air supply fans, E denotes exhaust fans

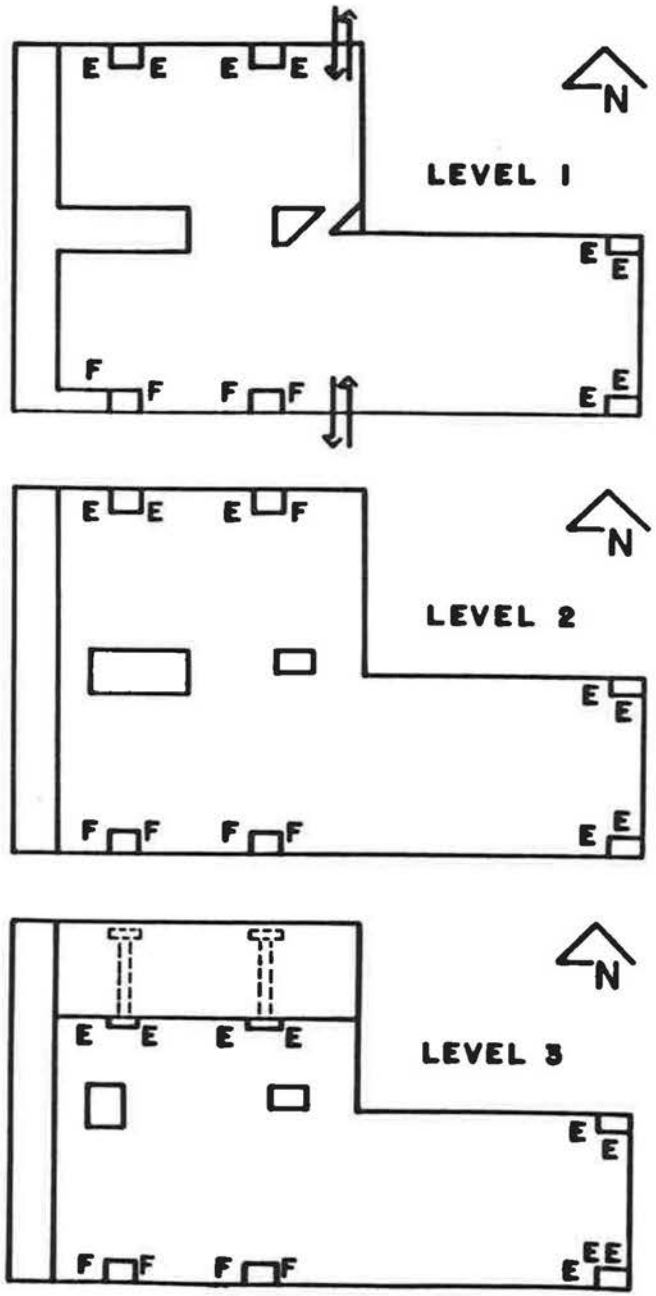


Figure 4. Modified configuration of fans in the parking garage; F denotes fresh air supply fans, E denotes exhaust fans

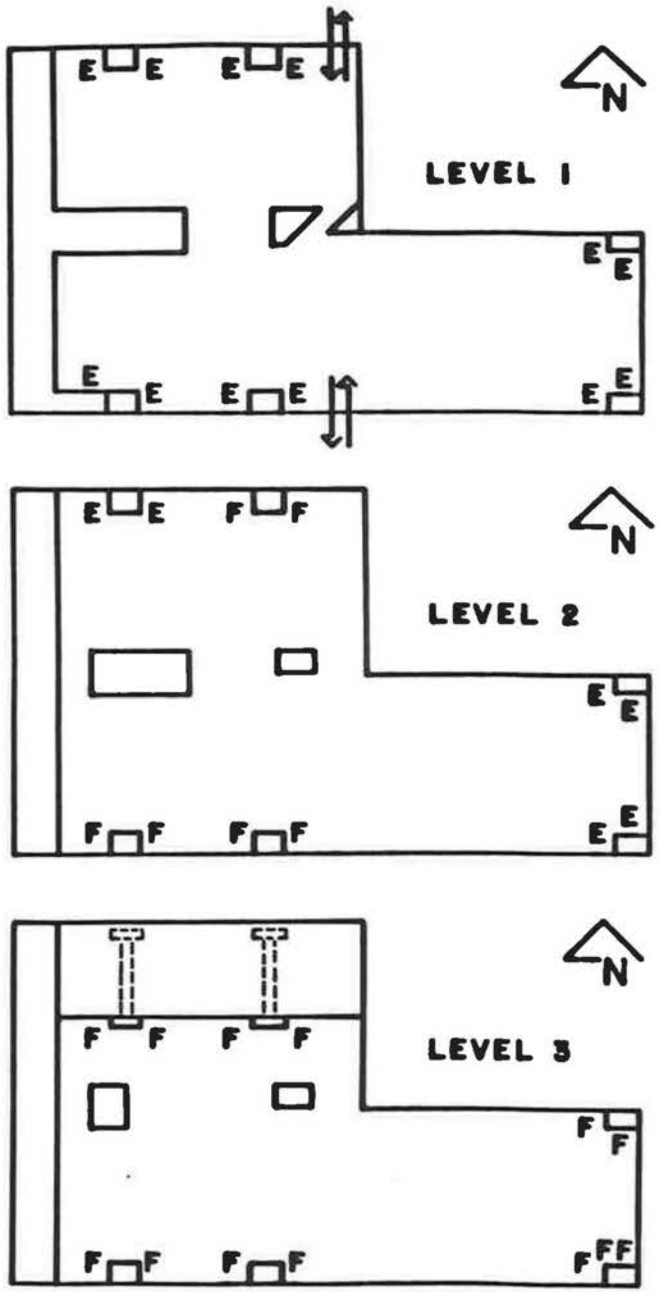


Figure 5. Recommended configuration of fans in the parking garage; F denotes fresh air supply fans, E denotes exhaust fans

Discussion

E.R. BRADLEY, E.I. DuPont, Charlotte, NC: Please comment on microbial duct cleaning techniques.

STERLING: Because the ducts were not found to be microbially contaminated (as stated in the text), the ductwork was not cleaned. However, the rooftop air-handling units, diffusers and walls in the occupied space were thoroughly washed with a dilute bleach solution.

H.T. GILKEY, Vienna, VA: Your paper reported higher carbon dioxide concentrations at desk level than at ceiling level and suggested that lowering the diffusers would increase penetration of supply air into the occupied zone. This should reduce stratification and reduce desk-level carbon dioxide concentrations. Were the diffusers lowered? What type of diffusers were they? Did management object to lowering the diffusers (in terms of appearance)? Were stratification and desk-top carbon dioxide concentrations improved?

STERLING: The diffusers have not yet been lowered in the library, although the building operators plan to implement the changes soon. Neither the building owners nor management have objected to this modification. After implementation, follow-up evaluation including measurement of carbon dioxide is planned to determine the effectiveness of the actions.

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Practical Control of Indoor Air Problems

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